日本人スポーツ選手の周辺を視る能力は劣っているのか

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序

サッカーなどの球技においては「視野が広い」、「周りがよく見えている」などの表現が広く用いられており、これらの表現は周辺視野の様々な状況の変化に対して素早く反応することの重要性を物語っている。しかし、これまで周辺視野における反応の早さに関する研究は非常に少なく、実際のスポーツの場面において周辺視野からの視覚情報が重要な役割を果たすことを考えると、周辺視野での反応の早さに関する研究の意義は大きいと考えられる。本研究では、周辺視野反応時間を指標として周辺視野での反応の早さに影響を与える要因について検討した。

サッカーは周囲の環境が刻々と変化する中で行うOpen−Skillを必要とする競技の代表例である。第1章では周辺視野からの視覚情報を日常的に用いているサッカー選手と、日常的にスポーツを行っていない一般大学生との間で周辺視野と中心視野の反応時間を比較した。その結果、大学サッカー選手は一般大学生と比較して周辺視野および中心視野での反応の早さに優れていることが明らかとなった。このことは、大学サッカー選手が生来的に素早く反応する能力を有していたか、あるいは日々のトレーニングによりその能力を向上させたことを示唆している。

この結果から、日常的にサッカーのトレーニングを行うことにより周辺視野反応時間が短縮する可能性があることが示唆された。そこで、周辺視野反応時間は周辺視野反応時間課題のトレーニングによって短縮するかどうかについて検討すると同時に、周辺視野反応時間のトレーニングと中心視野反応時間のトレーニングの間にみられる交互作用について検討した。被験者を周辺視野反応時間のトレーニング群と中心視野反応時間のトレーニング群に分け、両群ともに3週間にわたって反応時間のトレーニングを行った。周辺視野反応時間のトレーニング群では、トレーニングをした周辺視野だけでなく中心視野においても反応時間の短縮がみられた。中心視野反応時間

のトレーニング群においても、中心視野だけでなく周辺視野の反応時間にも短縮がみられた。これらの結果はトレーニングによりみられた反応時間の短縮が周辺視野および中心視野の反応時間に共通して含まれる中枢処理時間の短縮によることを示しており、主として運動に関連した中枢処理時間の短縮であることが推察される。さらに、周辺視野および中心視野の反応時間のトレーニング効果がトレーニング終了後にも維持されるのか、あるいはトレーニング開始前の水準にまで戻るのかについても検討した。その結果、周辺視野および中心視野の反応時間のトレーニング効果はトレーニング終了から3週間が経過しても維持されることが明らかとなった。スポーツの場面では広範囲にわたる視野の中で起きる様々な状況の変化に対して、的確に素早く対応することが要求される。従って、広い視野の中でどこに意識をおくかということがスポーツのパフォーマンスに大きく影響を及ぼすことが考えられる。

この問題は、心理学的には空間的注意の問題として捉えることができる。そこで、広範囲にわたる視野の中からランダムに視覚刺激を呈示する条件下において、ヒトは注意を等しく配分するのか、あるいは注意の配分に関して何らかの戦略をとるのかについて検討した。その結果、被験者は広い視野の中間の位置に対して能動的に注意を向けることが明らかとなった。これは、被験者が周辺視野を含む広範囲の中間の位置に能動的に注意を向けることにより、全ての視覚刺激に対してできるだけ素早く反応することを可能にする戦略を採っていたことを示唆している。

最後に、自転車エルゴメーターによる漸増負荷運動が周辺視野反応時間に与える影響について検討した。周辺視野反応時間は換気性作業閾値を超える高負荷の運動中において増加した。さらに、反応時間の増加(高負荷での運動中の反応時間から安静時の反応時間を引いた値)は最大酸素摂取量が高い被験者ほど小さいことが示された。高負荷での運動中にみられた周辺視

野反応時間の遅延は、激しい運動によって生じる脳内での生理的変化が、キー押し運動に関わる脳領域の活動低下を引き起こしたことに起因するものと推測され、運動中の反応時間の増加は脳への酸素供給と関連する可能性が示唆された。また、運動中にみられた周辺視野反応時間の遅延に対する心理学的要因として、高負荷での自転車運動と反応時間課題の二つの運動制御を同時に行うことによる注意の分散の影響も考えられる。

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両手同時ポインティング動作中の眼球運動制御

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1.Introduction

The visual system has the most complex neural circuitry of all the sensory system (Kandel, Schwartz, & Jessell, 2000). There is no doubt that vision is one of the most important sources of the sensory system. When considering the visual system, one must acknowledge that visual information is provided through both central and peripheral retinal areas, each specialized for processing specific types of information (Sivak & MacKenzie, 1992). Resolution of an object is low in peripheral vision. This fact does not mean that peripheral vision is inferior. Peripheral vision is used for organizing the spatial scene, whereas central vision is optimized for fine details.

A number of investigators have provided evidence that visual information is divided into two different cortical streams (ventral and dorsal). The division of visual information is traditionally separated into object and spatial vision (Mishkin, Ungerleider, & Macko, 1983) or color/form and motion vision (Van Essen & Maunsell, 1983) or perceptual identification of objects and sensorimotor transformation for visually guided actions (Goodale & Milner, 1992). The division can be traced back to the retina, where light is transduced into neural signals. The retinal ganglion cells can be subdivided into two different types: one of these two subdivisions terminates selectively in the parvocellular layer, while the other terminates in the magnocellular layer of the lateral geniculate nucleus (DeYoe & Van Essen, 1988; Livingstone & Hubel, 1988). Finally, 'ventral stream' of projection eventually reaches the inferotemporal cortex, while 'dorsal stream' terminates in the posterior parietal region (e.g. Goodale & Milner, 1992). It should be noted, however, that these two streams will often be simultaneously activated, thereby providing visual experience during skilled action (e.g. Goodale & Milner, 1992).

Ability to detect or recognize a visual stimulus can be analyzed by measuring reaction time (RT). RT is one of the many variables involved in psychomotor skill, and it is a prime determinant to evaluate psychomotor performance. Compared to literatures about RT for the central visual field, the number of studies which have shed light on RT for the peripheral visual field is few. RT for the peripheral visual field is longer than for central visual field and increases with increasing eccentricity (Rains, 1963; Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971; Osaka, 1976; Arkin & Yehuda, 1985). Cones are concentrated in the central portion of the retina and sharply decrease toward the periphery (Østerberg, 1935; Curcio, Sloan, Packer, Hendrickson, & Kalina, 1987; Curcio, Sloan, Kalina, & Hendrickson, 1990). The increase in RT with increasing eccentricity would be regarded as an expression of the gradual decrease in the relative cone density of the retina (Rains, 1963; Osaka, 1976).

Performance in ball sports would be closely associated with both physical and psychomotor skills. Although psychomotor skill is just one aspect of performance, the key difference between good performance and poor performance may be psychomotor skill as well as physical skill. During sports activity, we use peripheral vision as well as central vision to see what is happening. The ability to respond quickly based upon peripheral visual information would be a contributing factor to good performance in most sports. It is, therefore, important to psychophysiologically evaluate the RT for the peripheral visual field.

In ball sports such as soccer, players must pay attention not only to a moving ball but also to other players in their visual fields. Soccer players are required to make a quick decision and start to move as fast as possible on a basis of peripheral as well as central visual information. Therefore, soccer players would be required to have good peripheral visual perception. The visual demand on soccer players makes it tempting to suggest that soccer players may have superior peripheral perceptual abilities to nonathletes. Firstly, we have investigated whether soccer players have desirably high peripheral perception using RT measures.

People can acquire new motor skills and improve them with practice. Many researchers have reported that simple and choice RT decreases with practice within the area of the central visual field (e.g. Proctor, Reeve, Weeks, Dornier, & Van Zandt, 1991). These studies suggest that people can improve the speed of response to the stimulus presented in the central visual field. This would lead us to consider that RT for the peripheral visual field also decreases with practice even in a simple RT task. However, there is no study investigating the practice effects on RT for peripheral visual field. Moreover, we are curious whether or not the practice effects on the RT for the peripheral visual field extend to the RT for the central visual field, and vice versa. In the second study, we examined the practice effects on the RT for the peripheral and central visual fields and potential transfer effects. In addition, we investigated whether the practice effects established on the RT for the peripheral visual field are retained after retention interval once RT for the peripheral visual field decreases with practice.

We usually pay attention to the stimulus to which we are looking in the visual field. Posner (1980) proposed that orienting of attention as a central mechanism allows people to orient to a cued location in the absence of eye movement. Attention is controlled by partially segregated networks of brain areas (e.g. Corbetta & Shulman, 2002), and can be narrowly or widely focused depending on the task demands (e.g. Posner, 1980; Eriksen & St. James, 1986). Since objects in peripheral vision appear in low resolution, spatial attention would play an important role and it is meaningful to evaluate how attention can be distributed in the peripheral visual field. Thirdly, we have investigated using RT measures whether attention can be evenly distributed within the large area of the visual field, including both central and peripheral visual fields.

In competitive sports, participants are required to perform perceptual and decision-making tasks during strenuous exercise. Ability to maintain psychomotor skill during strenuous exercise is important for sports activities requiring a quick response to various external challenges. Since the psychomotor performance in the peripheral visual field during exhaustive exercise may be critical for performance in ball sports, it is necessary to accumulate the psychophysiological findings concerning the RT for the peripheral visual field during exhaustive exercise. The purpose of the fourth study was to examine the effect of incremental exercise on RT for the peripheral visual field.

2.Central and peripheral visual reaction time of soccer players and nonathletes

We have a tendency to rely upon vision as a source of sensory information (Magill, 1999). It is probable that vision is related to performance in ball sports. In ball sports such as soccer, for example, in defensive situations players must pay attention not only to a moving ball but also to other players in their visual fields during a game or daily training. A visual field is composed of central and peripheral components. Soccer players are required to make a quick decision and start to move as fast as possible on a basis of peripheral as well as central visual information. Therefore, soccer players are required to have good peripheral visual perception.

The ability to detect or recognize a visual stimulus can be analyzed by measuring reaction time (RT). It is known that peripheral visual RT may increase, in comparison to central RT, when the visual angle is increased (Østerberg, 1935; Rains, 1963; Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971; Borkenhagen, 1974; Osaka, 1976; Arkin & Yehuda, 1985). However, there are few studies investigating the peripheral visual RT for athletes involved in ball sports and in nonathletes. The visual demands on soccer players makes it tempting to suggest that soccer players may have inherited or developed superior peripheral perceptual abilities to nonathletes.

The aim of the present study was to investigate whether soccer players have desirably high peripheral perception using RT measures. Soccer players must track moving balls and other players in their visual fields at different distances, indicating that soccer players must respond to objects of diverse size. For that reason, we used three different sizes of stimuli to clarify to what extent the RT differed between soccer players and nonathletes measured in response to different sizes of stimuli. The three stimulus sizes used in the present experiment are considered to correspond to perceived ball sizes on a playing field.

Posner, Snyder, and Davidson (1980) have reported that RT to extrafoveal peripheral stimulus was shorter at expected positions and longer at unexpected positions. In a game or daily training of ball sports, players are required to respond to the unexpected direction. Therefore, we measured peripheral RT randomly presented in near or far peripheral positions to clarify whether soccer players show quicker response than nonathletes to the stimulus presented in the unexpected peripheral positions.

RT may be fractionated into premotor and motor components based upon the difference between the start of electromyogram (EMG) and onset of movement (Weiss, 1965). To the authors' knowledge, no report has been published which measured EMG onset, i.e., Premotor Time, during peripheral visual RT tasks. In the present study, central and peripheral RT measures were fractionated into Premotor Time and Motor Time, corresponding to the nervous system's processing time and muscle contraction time, respectively.

METHOD

Subjects

Six male university soccer players and six university students (2 women and 4 men) volunteered to take part in this study. University soccer players (*M* age=21.5 yr., *SD*=1.4) had an average of 9.3 yr. (*SD*=0.8) of experience in playing soccer. All of them are intermediate soccer players (not experts). University students (*M* age=22.8 yr., *SD*=0.8) had no experience of soccer or other ball sports training. All subjects reported normal visual acuity either unaided or while wearing their own corrective lenses. The subjects were considered right handed as all wrote with the right hand.

Apparatus

A computer (NEC PC9821) was used to control visual stimulus presentation and record RT on each trial. A visual stimulus was presented on a computer screen. All visual conditions were conducted using binocular vision. The subject's head rested on a head chin rest 30 cm away from the computer screen (3 cd/m^2) so the eyes were directly in front of and level with the position of the fixation point. The exposure duration of visual stimuli was programmed at 50 msec. Four intertrial intervals (2, 3, 4, and 5 sec.) were randomly used. They were also served as the fore-periods. The subjects responded to the onset of each stimulus by depressing the space key of the computer as fast as possible. The response key was manipulated using the index finger of the right hand.

Procedure

The experiment was carried out in the following four conditions: (I) central RT,

(Ⅱ) peripheral simple RT in near position, (Ⅲ) peripheral simple RT in far position, and (Ⅳ) peripheral RT randomly presented in near or far position. The stimulus in all conditions was in the shape of a ring (14 cd/m²). The size of the stimulus was varied as follows: large size 8 mm in diameter (1.52° in central vision), medium size 4 mm (0.76°), or small size 2 mm (0.38°).

In the Central condition, the stimulus was presented at the fixation point. The stimulus in the Near Peripheral position was presented at an angle of 10° to the right from the midpoint of a subject's eyes. The stimulus in the Far Peripheral position was presented at an angle of 30° to the right from the midpoint of the subjects' eyes. In the Random Peripheral condition, the stimulus was randomly presented at either Near or Far peripheral position. In all the peripheral conditions, the fixation point remained illuminated throughout the experiments. The subjects were instructed to fixate their eyes on the fixation point all the time.

Experimental conditions of (Ⅰ), (Ⅱ), and (Ⅲ) comprised 20 trials for each size. The Random Peripheral condition (Ⅳ) comprised 40 trials for each size; 20 trials were randomly performed at each position. Each session consisted of a combination of four experimental conditions and three sizes (12 sessions) intermixed in a randomized order. In each session, the stimulus size and condition were constant all the time. Before the experiments, the subject was visually familiarized with the stimuli and given 10 practice trials in each of 12 sessions.

The electromyogram (EMG) was recorded from the flexor digitorum superficialis muscle of the responding forearm. RT was fractionated into Premotor Time and Motor Time. Premotor Time was the time from stimulus onset to the appearance of the muscle action potential. Motor Time was the duration from muscle EMG to the key-press response (Weiss, 1965).

In additional experiments horizontal components of eye movement were measured by an infrared reflection system (T.K.K. 2930a Takei Scientific Instruments Co., Ltd., Japan) from four subjects (two soccer players and two nonathletes), showing that they could hold their eyes on the fixation point during each experimental condition.

Statistical Analyses

Separate three-way mixed-design analysis of variance was used on the RT, Premotor Time, and Motor Time with group and size as the between-group factors, and condition as the within-group factor. Differences with a probability level of $<.05$ were designated as significant.

RESULTS

Reaction Time

Table 1 shows the means and standard deviations of the RT. A three-way analysis of variance on RT yielded significant main effects of size of the stimulus and condition ($F_{2,30}$=4.43, p<.05 and $F_{4,120}$=85.53, p<.001, respectively). There were no significant main effects of group and no significant interactions. As no difference was shown in RT between both groups, we combined the RTs of both groups.

Table 1 Reaction Times (msec.) of Soccer Players and Nonathletes by Condition and Size of Stimulus

Stimulus Size	Group	Condition				
		Central Visual	Simple Near	Simple Far	Random Near	Random Far
Large	Soccer Players					
	M	243	242	255	260	268
	SD	7.31	6.77	7.81	7.39	3.83
	Nonathletes					
	M	246	250	260	265	274
	SD	15.63	10.41	10.3	14.3	14.37
Medium	Soccer Players					
	M	252	251	258	262	270
	SD	14.78	12.39	5.75	11.9	5.95
	Nonathletes					
	M	252	255	270	269	272
	SD	13.81	8.57	13.05	13.27	12.73
Small	Soccer Players					
	M	249	256	268	268	279
	SD	7.03	4.54	8.89	11.58	7.28
	Nonathletes					
	M	260	266	273	274	286
	SD	14.25	18.88	14.01	11.46	12.11

One-way analysis of variance with conditions as between-factor showed significant main effects of the condition for the large size ($F_{4,59}$=14.15, p<.001), for the medium size ($F_{4,59}$=6.32, p<.001), and for the small size ($F_{4,59}$=9.85, p<.001).

Premotor Time

Table 2 shows the means and standard deviations of the Premotor Time. A three-way analyais of variance on Premotor Time gave significant main effects for group, size of the stimulus, and condition ($F_{1,30}$=13.45, p<.01; $F_{2,30}$=6.89, p<.01; and $F_{4,120}$=273.43, p<.001, respectively). There were no significant interactions. The Premotor Times for the soccer players were shorter than those for the nonathletes. Further analyses for the soccer players and for the nonathletes were performed separately.

Table 2 Premotor Times (msec.) of Soccer Players and Nonathletes by Condition and Size of Stimulus

Stimulus Size	Group	Condition				
		Central Visual	Simple Near	Simple Far	Random Near	Random Far
Large	Soccer Players					
	M	167	168	182	185	192
	SD	6.98	5.37	8.57	5.34	5.96
	Nonathletes					
	M	175	177	190	191	198
	SD	10.91	10.03	8.02	9.42	7.36
Medium	Soccer Players					
	M	173	178	183	187	196
	SD	11.02	14.9	6.56	11.02	5.04
	Nonathletes					
	M	180	184	196	197	202
	SD	8.33	4.22	8.04	8.88	6.95
Small	Soccer Players					
	M	173	182	190	191	206
	SD	4.75	5.01	6.44	8.45	5.73
	Nonathletes					
	M	183	190	198	200	209
	SD	6.77	13.52	7.57	8.72	7.97

A two-way analysis of variance was used on the Premotor Time of each group with size as the between factor and condition as the within factor. There was a significant main effect of the size of the stimulus for the soccer players ($F_{2,15}$=4.84, p<.05), while there was no significant main effect of the size of the stimulus for the nonathletes.

Table 3 Motor Times (msec.) of Soccer Players and Nonathletes by Condition and Size of Stimulus

Stimulus Size	Group	Condition				
		Central Visual	Simple Near	Simple Far	Random Near	Random Far
Large	Soccer Players					
	M	77	74	73	75	77
	SD	4.03	4.41	4.86	3.72	6.97
	Nonathletes					
	M	71	73	70	74	76
	SD	10.07	9.39	6.85	6.97	8.7
Medium	Soccer Players					
	M	79	72	76	74	74
	SD	6.41	5.05	2.07	5.28	2.83
	Nonathletes					
	M	72	71	74	73	70
	SD	7.92	6.23	5.72	6.85	8.91
Small	Soccer Players					
	M	76	75	78	77	73
	SD	4.94	1.76	3.62	10.8	3.14
	Nonathletes					
	M	77	76	75	74	77
	SD	9.33	8.57	8.26	4.86	9.87

A one-way analysis of variance was used for each group and for each size of the stimulus with condition as the between factor. For the Premotor Time of the soccer players, there were significant main effects of the condition for the large size ($F_{4,29}$=16.53, p<.001), for the medium size ($F_{4,29}$=4.33, p<.01), and for the small size ($F_{4,29}$=23.51, p<.001). For the Premotor Time of the nonathletes, there were significant main effects of the condition for the large size ($F_{4,29}$=6.52, p<.01), for the medium size ($F_{4,29}$=9.19,

$p<.001$), and for the small size ($F_{4,29}=7.01$, $p<.01$).

Motor Time

Table 3 shows the means and standard deviations of the Motor Time. A three-way analysis of variance on Motor Time yielded no significant main effects for group, size of the stimulus, and condition. There were no significant interactions.

DISCUSSION

Many investigators have examined factors related to visual perception in peripheral vision such as visual resolution (Kerr, 1971), visual angle and apparent size of objects (Newsome, 1972), area-intensity interaction (Dwyer & White, 1974), target size and luminance in apparent brightness (Osaka, 1975) and information-processing speed (Williams, 1984). RT has been measured in central and peripheral visual fields, and the differences in RT to the stimulus presented to the fovea and periphery can be explained in terms of relative decrease of cone density function (Østerberg, 1935). Since that seminal work, many researchers have shown that RT to centrally located stimulus is faster than to peripherally located stimulus (Rains, 1963; Berlucchi, *et al.*, 1971; Borkenhagen, 1974; Osaka, 1976; Arkin & Yehuda, 1985).

The present study showed that the longer peripheral visual RT compared to the central one was preceded by an increased Premotor Time. Premotor Time is time needed to organize centrally, translate, and channel the appropriate commands to the musculature responsible for initiating the desired response (Fischman, 1984). That the RTs found in the Peripheral conditions were longer than those in the Central condition is considered to reflect a longer premotor process.

In the present study, no differences were shown in RTs in central and peripheral visual fields between groups. However, Premotor Times of soccer players were significantly shorter than those of nonathletes. It has been widely assumed that Premotor Time is a more valid indicator of programming time than RT (Weiss, 1965; Botwinick & Thompson, 1966; Fischman, 1984). This suggests that soccer players have higher perceptual abilities to respond quickly in peripheral as well as central visual fields. It can be speculated that soccer players might have inherited the peripheral perceptual abilities to respond quickly or developed higher abilities than nonathletes.

Helsen and Starkes (1999) reported that no differences were shown in central and peripheral RTs between expert and intermediate soccer players. This seems to be inconsistent with our result. However, there are two differences between the work of Helsen and Starkes and the present study: (1) peripheral visual angle used was different from our experiment, (2) the study by Helsen and Starkes was aimed to compare the differences between experts and intermediate soccer players, while our study was aimed to compare the difference between intermediate university soccer players (not experts) and nonathletes who have no experience in ball sports. It is, therefore, considered that the result by Helsen and Starkes cannot be directly compared with the result of the present study.

Starkes (1987) reported that the expert sports performer's visual advantage is not related to the physical structure of their visual system but rather to how they pick-up, process, and utilize the visual information specific to their domain of expertise to guide their actions. Basic visual functioning is not the limiting factor to sports performance (Abernethy & Neal, 1999). Moreover, accounts of successful athletes with inferior vision have been reported (Starkes, 1984; Helsen & Starkes, 1999; Williams, Davids, & Williams, 1999). The shorter premotor time for the soccer players in the present study may not directly predict skilled sports performance.

Reaction Time decreases as a function of increasing target size (Edwards & Goolkasian, 1974; Osaka, 1976). In the present study, the RTs and Premotor Times for both groups decreased with increasing stimulus size. This is consistent with the above previous studies. The analyses for the Premotor Times gave a significant main effect of the size of the stimulus for the soccer players, while there was no significant main effect of the size of the stimulus for the nonathletes. In the present study, the small sample might provide low power to detect a significant main effect of the size of the stimulus for the nonathletes.

The experienced soccer players have demonstrated superior anticipatory performance to that of inexperienced players (Williams, Davids, Burwitz, & Williams, 1994). Soccer players acquire an extensive soccer-specific knowledge base that enables them to recognize meaningful associations between the positions and movements of players in game situations (Williams, Davids, Burwitz, & Williams, 1993). Elite volleyball and basketball athletes were more efficient in predicting offensive games (Kioumourtzoglou, Kourtessis, Michalopoulou, & Derri, 1998). In the 'Random Peripheral conditions of the present study, anticipation and soccer-specific knowledge base were not required. Therefore, there were no evident differences for the effect of condition between soccer players and nonathletes.

In conclusion, Peripheral visual RT was longer than central visual RT given an increment in premotor time. Soccer players showed shorter Premotor Times than nonathletes, suggesting that soccer players have quicker perceptual response in peripheral and central visual fields.

3.Practice effects on reaction time for peripheral and central visual fields

Vision is important for processing information about spatial location of an object. Ability to detect or recognize a visual stimulus can be analyzed by measuring reaction time (RT). A visual field is composed of central and peripheral components. It is known that RT for peripheral visual field increases, in comparison with RT for the central visual field, when the visual angle of a stimulus is increased (Rains, 1963; Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971; Osaka, 1976; Arkin & Yehuda, 1985; Ando, Kida, & Oda, 2001).

People can acquire new motor skills and improve them with practice. Many researchers have investigated whether RT decreases with practice. Mowbray and Rhoades (1959), Aiken and Lichtenstein (1964), Norrie (1967), Morris (1977), Clarkson and Kroll (1978), Proctor and Reeve (1988), and Proctor, Reeve, Weeks, Dornier, and Van Zandt (1991) reported that simple and choice RTs decrease with practice. More recently, Taniguchi (1999) demonstrated that simple RT for thumb flexion decreases with practice. According to these studies, it is likely that RT decreases with practice within the area of the central visual field. However, there is no study of practice effects on RT for peripheral visual field. The first aim of the present study was to investigate whether RT for peripheral visual field decreases with practice.

Does the RT for central visual field decrease with the decrease in the RT for peripheral visual field? Does the RT for peripheral visual field decrease with the decrease in the RT for central visual field? To answer these questions, the second aim of the present study was to investigate whether the practice effects on the RT for peripheral visual field extend to the RT for central visual field, and vice versa.

METHOD

Subjects

Sixteen male university students (*M* age=22.3 yr., *SD*=1.4) volunteered to participate. They were divided into two groups (*ns*=8); one practiced using peripheral vision and the other practiced using central vision. All subjects reported normal visual acuity either unaided or while wearing their own corrective lenses. The subjects all wrote with their right hand. The right eye of 12 subjects was dominant for sighting and the left for the remaining four.

Apparatus

A computer (NEC PC9821) was used to control visual stimulus presentation on a computer screen and record the RT of each trial (Ando, *et al.*, 2001). All visual conditions were conducted using binocular vision. The subject's head rested on a head and chin rest that was placed 30 cm from the computer screen (3 cd/m^2) so the eyes were directly in front of and at the same level as the position of the fixation point. The exposure duration of the visual stimulus was 50 msec. Four trial intervals (2, 3, 4 and 5 sec.) were randomly used. They also served as the foreperiods. Subjects responded to the onset of each stimulus by pressing the space key of the computer as fast as possible. The response key was manipulated using the index finger of the right hand.

Procedure

Electromyogram (EMG) was measured from the flexor digitorum superficialis muscle of responding forearm. EMG-RT is the time from stimulus onset to the appearance of the electromyogram (EMG). EMG-RT is a valid indicator of programming time (Weiss, 1965; Botwinick & Thompson, 1966; Fischman, 1984). Morris (1977) reported that decrease in the RT with practice reflected changes in the premotor component. Therefore, the term of RT used in the present study means EMG-RT.

Before and after the date of practice, RT was measured under the following three conditions: (I) Central condition, (II) Near Peripheral condition, and (III) Far Peripheral condition. The stimulus 8-mm diameter (1.52° in central vision) in all conditions was in the shape of a ring (14 cd/m²). In the Central condition, the stimulus was presented at the fixation point and in the Near Peripheral condition at an angle of 10° to the right from the midpoint of the subject's eyes. The stimulus in the Far Peripheral condition was presented at an angle of 30° to the right from the midpoint of the subjects' eyes. In the Peripheral conditions, the fixation point remained illuminated throughout the experiments. The subjects were instructed to keep their eyes on the fixation point. Horizontal components of eye movement were also measured by an infrared reflection system (T.K.K. 2930a Takei Scientific Instruments Co., Ltd., Japan) and showed that they could hold their eyes on a fixation point throughout each response.

One experimental block consisted of a series of 25 trials. Experimental conditions of (I), (II), and (III) were tested in a random order. The condition was constant during each block. Ten trials were given before the experiment in each block. During the practice period, the group practicing using peripheral vision practiced RT tasks in the Far Peripheral condition. The group practicing using central vision practiced RT tasks in the Central condition. Each group practiced three blocks five days a week for three weeks.

RESULTS

Two-way analysis of variance was performed on the RT before practice with group as the between factor and condition as the within factor (Table 1). There was no significant main effect of group, indicating no difference in the RT between groups before practice.

Table 1 Analysis of Variance of Reaction Time before Practice

Source	*df*	*MS*	*F*	*p*
Subjects	14	370.20		
Group	1	760.02	2.05	
Condition	2	1624.52	54.15	<.001
Condition × Group	2	70.77	2.36	
Subjects × Condition	28	30.00		
Total	47			

Table 2 RT (msec.) for Each Group by Condition and Measurement Time

Group	Before Practice		After Practice	
	M	SD	M	SD
Group Practicing Using Peripheral Vision (n=8)				
Central Condition	172	13	163	9
Near Peripheral Condition	172	9	166	13
Far Peripheral Condition *	192	15	174	11
Group Practicing Using Central Vision (n=8)				
Central Condition *	178	9	167	14
Near Peripheral Condition	185	12	169	17
Far Peripheral Condition	197	12	179	19

* Asterisk indicates that the subjects practiced RT task in this condition.

Table 2 shows the means and standard deviations of the RT for each group by condition and measurement time. Three-way mixed design analysis of variance was used on the RTs, with group as the between factor and measurement time and condition as the within factors (Table 3). There was a significant main effect of measurement time, indicating that the RT for central and peripheral visual fields decreased with practice for each group. A main effect of condition was significant, showing that the RT for peripheral visual field was longer than the RT for central visual field before and after practice. The present results suggest that the practice effects on the RT in the Peripheral condition extended to the RT in the Central and the Near Peripheral conditions and that the practice effects on the RT in the Central condition extended to the RT in the Near Peripheral and the Far Peripheral conditions.

Table 3 Three-way Analysis of Variance of Reaction Time

Source	*df*	*MS*	*F*	*p*
Subjects	14	789.86		
Group	1	888.17	1.12	
Measurement time	1	4030.04	36.61	<.001
Measurement time × Group	1	84.38	0.77	
Subjects × Measurement time	14	110.09		
Condition	1.42	3017.67	63.70	<.001
Condition × Group	1.42	33.09	0.70	
Subjects × Condition	19.89	47.37		
Measurement time × Condition	2	115.07	3.07	
Measurement time × Condition × Group	2	50.91	1.36	
Subjects × Measurement time × Condition	28	37.55		
Total	85.73			

DISCUSSION

Many researchers have measured RT for central and peripheral visual fields. RT for responding to stimuli in the peripheral visual field is longer than the RT for those in the central visual field (Rains, 1963; Berlucchi, *et al.*, 1971; Osaka, 1976; Arkin & Yehuda, 1985; Ando *et al.*, 2001). That RT for peripheral visual field is longer than RT for central visual field can be explained by the relative decrease of cone density (Østerberg, 1935; Curcio, Sloan, Kalina, & Hendrickson, 1990).

In the present study, RT for peripheral visual field decreased with practice. Moreover, what is an interesting result was that the practice effects on the RT for peripheral visual field extended to the RT for central visual field, and vice versa. Schmidt and Lee (1999) proposed that transfer of motor learning depends on the similarity between tasks. It is quite likely that there is a similarity in RT tasks between the Central and the Peripheral conditions because the manual responses by using the index finger were the same in these conditions. Therefore, transfer suggests the decrease in the RT may have resulted from a decrease in the central nervous system's processing time in common between the Central and the Peripheral conditions.

In conclusion, RT for peripheral visual field as well as for central visual field decreased with practice. Practice effects on the RT for peripheral visual field extended to the RT for central visual field, and vice versa.

4 .Retention of practice effects on simple reaction time for peripheral and central visual fields

People can improve the ability to respond quickly with practice. Recently, we have reported that reaction time (RT) for both peripheral visual field and central visual field decreases with practice (Ando, Kida, & Oda, 2002). The practice effects established on the RT for peripheral visual field transferred to the RT for central visual field, and vice versa. The transfer effects suggest that the decrease in the RT resulted from a decrease in the central nervous system's processing time that exists in common between two RT tasks.

Proctor, Reeve, Weeks, Dornier, and Van Zandt (1991) investigated whether or not practice effects on choice RT using spatial precuing and symbolic cuing tasks were retained after a 1-week retention interval. They have indicated that the response selection procedures acquired with practice are retained fairly well for at least a 1-week period. Compared to literatures about the practice effects on simple and choice RT (see references in Ando, *et al.*, 2002), few studies have addressed how permanent the practice effects on RT are, i.e. how well the effects are retained. There is no study investigating the retention of practice effects on simple RT for peripheral visual field. The present study investigated the retention of practice effects on simple RT for peripheral and central visual fields. It is important to behaviorally evaluate the retention of the practice effects since the retention suggests that changes in neural correlates with practice are lasting after retention interval.

METHOD

Subjects

Sixteen male university students (*M* age=22.3 yr., *SD*=1.4) volunteered to participate. They were randomly divided into two groups of the same age (*n*s=8); one practiced using peripheral vision and the other practiced using central vision. All subjects reported normal visual acuity either unaided or while wearing their own corrective lenses. The subjects all wrote with their right hand.

Apparatus

A computer (NEC PC9821) was used to control visual stimulus presentation and record the RT for a key press throughout the experiments. All visual conditions were conducted using binocular vision. The subject's head rested on a head and chin rest placed 30 cm from the computer screen (3 cd/m^2) so the eyes were directly in front of and at the same level as the position of the fixation point. The exposure duration of the visual stimulus was 50 msec. Four inter-trial intervals (2, 3, 4, and 5 sec.) were randomly used. They also served as the fore-periods. The stimulus 8-mm diameter (1.52° in central vision) in all conditions was in the shape of a ring (14 cd/m^2). The contrast ratio was 0.65, and the sign of the contrast was bright (white on black background). Subjects responded to the onset of each stimulus by pressing the space key of the computer as fast as possible. The response key was manipulated using the index finger of the right hand.

Electromyograms (EMG) were measured from the flexor digitorum superficialis muscle of responding forearm. EMG-RT is the time from stimulus onset to the appearance of the electromyogram (EMG). Morris (1977) and Ando, *et al.* (2002) have reported that decrease in the RT with practice reflected changes in the premotor components. Therefore, EMG-RT was used as the index to assess the practice effects.

Testing Procedure

Before practice, after the date of practice, and three weeks after practice, RT for the key press and EMG-RT was measured in the following three retinal positions: (Ⅰ) Central condition, (Ⅱ) Near Peripheral condition, and (Ⅲ) Far Peripheral condition. In the Central condition, the stimulus was presented at the fixation point and in the Near Peripheral condition was presented at an angle of 10° to the right from the midpoint of the subject's eyes. The stimulus in the Far Peripheral condition was presented at an angle of 30° to the right from the midpoint of the subjects' eyes. In the Peripheral conditions, the fixation point remained illuminated throughout the experiments. The subjects were instructed to keep their eyes on the fixation point. One experimental block consisted of a series of 25 trials. Before each block, the subjects were visually familiarized with the stimuli and given ten practice trials. Experimental conditions of (Ⅰ), (Ⅱ), and (Ⅲ) were tested in a randomized order. The condition was constant during each block. Horizontal components of eye movement were measured by an infrared reflection system (T.K.K. 2930a Takei Scientific Instruments Co., Ltd., Japan) and showed that subjects could hold their eyes on a fixation point throughout each response.

Practice Procedure

During the practice period, the group practicing using peripheral vision practiced RT tasks in the Far Peripheral condition. The group practicing using central vision practiced RT tasks in the Central condition. Each group practiced three blocks five days a week for three weeks for a total of 1125 trials. During the practice period, RT for the key press was recorded for each group. The RT for the key press before practice, during the practice period, and after practice was analyzed to confirm that subjects' performance had peaked with practice. The RT for the key press during the practice period was averaged by week for each group.

RESULTS & DISCUSSION

Table 1 shows the means and standard deviations of the RT for the key press before practice, during the practice period, and after practice for each group. Friedman's nonparametric one-way analysis of variance was performed on the RT between times of measurement for each group, indicating that mean RT significantly differ between times of measurement for the group using peripheral vision [χ_4^2, (N=8)=18.66, p<.05] and for the group practicing using central vision [χ_4^2, (N=8)=21.70, p<.05].

A Wilcoxon Paired Signed Rank Test showed that the RT before practice was significantly larger than the other times of measurement for each group (p<.05, respectively). The RT at the first week during the practice period was significantly larger than that at the second week during the practice period in the group practicing using peripheral vision ($p<.05$). The RT at the first week during the practice period was significantly larger than that at the second and third weeks during the practice period in the group practicing using central vision ($p<.05$, respectively). There were no significant differences in the RT between after practice and at each week during the practice period.

Table 1 RT (msec.) for a key press before practice, during the practice period, and after practice for each group

Measure	Time of Measurement				
	Before Practice	Week 1	Week 2	Week 3	After Practice
The Group Practicing Using Peripheral Vision (n=8)					
Far Peripheral Condition					
M	265	249 *	239 * †	243 *	243 *
SD	14	13	11	17	16
The Group Practicing Using Central Vision (n=8)					
Central Condition					
M	245	238 *	227 * †	229 * †	232 *
SD	14	14	12	13	16

Note. Mean RT during the practice period was averaged by week.

* Significant difference with the RT before practice for each condition. (p<.05)

† Significant difference with the RT at the first week during the practice period for each condition. (p<.05)

It was suggested that the majority of practice effects for both groups occurred during the first block, which was defined before practice in the present study, and the first week of the practice period. Afterward, the RT leveled off and almost unchanged. Therefore, we can assume that subjects' performance had peaked after the practice period had elapsed.

Three-way analysis of variance was performed on the EMG-RT with condition and time of measurement as the within factors and group as the between factor. A main effect of group was not significant ($F_{1,14}$=0.99), indicating that there were no differences in the RT between groups. The interaction of time of measurement by condition was significant ($F_{4,56}$=3.39, p<.05). One-way analysis of variance was performed for each condition. There were significant main effects of time of measurement for the Central, the Near Peripheral, and the Far Peripheral conditions ($F_{2,30}$=24.39, p<.001; $F_{2,30}$=10.17, p<.001; $F_{2,30}$=26.83, p<.001, respectively).

EMG-RT for both groups was summarized for further analysis as there were no differences between groups and no interactions related to group (Table 2). The multiple comparisons by the Tukey HSD showed that the EMG-RT after practice was shorter than the EMG-RT before practice for the Central, the Near Peripheral, and the Far Peripheral conditions (p<.001, p<.01, and p<.001, respectively).

The multiple comparisons also indicated that the EMG-RT three weeks after practice was shorter than the EMG-RT before practice for the Central, the Near Peripheral, and the Far Peripheral conditions (p<.001, p<.01, and p<.001, respectively). No differences were observed between the EMG-RT after practice and the EMG-RT three weeks after practice for each condition. These results indicated that the practice effects and the transfer effects were maintained over the retention interval, suggesting that once

Table 2 EMG-RT (msec.) for all subjects by condition and time of measurement

Measure	Time of Measurement		
	Before Practice	After Practice	3 Weeks After Practice
Central Condition			
M	175	165 ***	161 ***
SD	11	15	13
Near Peripheral Condition			
M	179	167 **	167 **
SD	12	15	14
Far Peripheral Condition			
M	194	177 ***	182 ***
SD	13	15	18

* Significant difference with the EMG-RT before practice for each condition.

*** $p<0.001$ ** $p<0.01$

simple RT for peripheral and central visual fields decreases with practice, the improved performances are stable and retained for at least three weeks. Visual information is processed in various ways until eventually it is output as observable motor activity. It appears that once the neural correlates of responding quickly are improved, the improved performances are retained for at least three weeks. Further investigation would be needed to ascertain whether or not the practice effects on simple RT are retained for longer periods than this.

5.Attention can be oriented to intermediate locations within the large area of the visual field

In the real world, we are always moving our eyes to stimuli, and thus we are habitually paying attention to the stimulus to which we are looking in the visual field. Posner (1980) proposed that orienting of attention as a central mechanism allows people to orient to a cued location in the absence of eye movement. It is assumed that attention can be narrowly or widely focused depending on the task demands (Posner, 1980; Posner, Snyder, & Davidson, 1980; Eriksen & Yeh, 1985; Eriksen & St. James, 1986), and that attention cannot be distributed to nonadjacent regions (e.g., McCormick, Klein, & Johnston, 1998). The ability to detect or recognize a stimulus in the visual field can be analyzed by measuring reaction time (RT). Numerous experiments have shown that RT is faster when attention is focused on one point of the visual field than when attention is distributed among many elements across the entire visual field because the attentional resources are limited (e.g., Ericksen & Yeh, 1985).

The visual field is composed of central and peripheral components, and information presented in the central and peripheral visual fields is provided through both central and peripheral retinal areas. Many researchers have investigated the orienting of attention in the central visual field. However, there are few studies investigating orienting of attention within large area including both central and peripheral visual fields.

The purpose of the present study was to investigate whether attention can be evenly distributed within the large area of the visual field. In the present study, the RT was measured in the two conditions, i.e., Fixed Location condition and Random Location condition. In the Fixed Location condition, the trials are fixed in such a way that the stimulus appears repeatedly at the same location. Therefore, attention can be narrowly focused in this condition, so that the stimulus occurring within a specific region may be processed more rapidly. In the Random Location condition, the stimulus was presented at one of four locations as determined randomly with equal probability. Assuming that areas of visual space where attention is distributed may be defined as those in which an improved efficiency in performance is measured, the differences in RT between the Fixed Location and the Random Location conditions may be interpreted as being largely attributable to the effects of attentional focus. Therefore, it is hypothesized that, if attention is evenly distributed within the large area of the visual field in the Random Location condition, mean differences in RT for the Fixed Location and the Random Location conditions may not be statistically significant despite the varied stimulated locations. On the other hand, if attention is not evenly distributed within the large area of the visual field and is oriented to some specific locations in the Random Location condition, RT for the locations to which attention is specifically oriented in the Random Location condition may not differ from RT for the same location measured in Fixed Location condition.

METHOD

Subjects

The subjects were 22 male university students (M age= 22.3yr., SD=2.7). All subjects had normal visual acuity either unaided or while wearing their own corrective lenses. They were all right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). The right eye was dominant for sighting in 17 subjects and the left by the remaining 5. The dominant eye was determined with the "hole-in-the-card" test (Brod & Hamilton, 1971).

Apparatus

A computer and RT measurement apparatus (Qtec. Co., Ltd., Japan) were used to control the visual stimulus presentation and record the RT of each trial. A visual stimulus was presented on a computer screen. Each subject sat in front of the computer screen in a dark room, with the head on a chin rest 30 cm from the computer screen so the eyes were directly in front of and level with the position of the fixation point. To dark adapt they remained in the dark room for 5 min. prior to responding. The horizontal components of eye movement were measured by an infrared reflection system (T.K.K. 2930a Takei Scientific Instruments Co., Ltd., Japan). Eye movements in excess of 1° of visual angle were detected and discarded without replacement.

Stimulus

The background of the visual display was composed of a blue fixation cross ($0.38° \times 0.38°$, 2.0 cd/m²) presented on a black background (1.0×10^{-4} cd/m²). The subjects were instructed to keep their eyes on the cross that remained illuminated throughout the experiments. The visual stimulus was a white filled circle, 2 mm in diameter (0.38° in central vision, 22.0 cd/m²). The exposure duration of the visual stimulus was 50 msec. Trial intervals were 2, 3, 4 and 5 sec. These intervals were randomly ranged on each trial interval, and they also served as the foreperiods. The stimulus was presented at one of four possible locations on the horizontal meridian of the visual field. The stimulated locations were the fixation point (0°), 10°, 20°, and 30° to the right. The subjects responded to the onset of each stimulus by pressing the response key as fast as possible. The response key was manipulated using the index finger of the right hand. All visual conditions were conducted using both eyes.

Procedure

The experiment was conducted using fixed locations and randomized locations as conditions (Fixed Location and Random Location conditions). A training period of 20 trials was allowed prior to each condition. Each block was comprised of 20 trials in each condition. In the Fixed Location condition, the stimulus was presented at one fixed location repeatedly for one block and then shifted to a new location. The first location and a new location to which shifting was done were randomly ordered. In the Random Location condition, the stimulus was presented randomly at one of four locations with equal probability on every trial. The subjects performed four blocks so that the number of trials totaled 20 at each location. Half of the subjects, who were randomly assigned, were tested first with the Fixed Location condition, and half were tested first with the Random Location condition.

Statistical Analyses

Two-way analysis of variance with repeated measures was performed on the RT with Condition and Location as the within factors. Tukey's method was used as *post-hoc* multiple comparisons. Mean differences with a probability level of <.05 were designated as significant.

RESULTS

Fig.1 shows the means and standard deviations of the RT for each Condition and Location. Two-way analysis of variance showed that the Condition × Location interaction was significant ($F_{3,63}$=9.72, p<.001). Further analyses were performed for each condition and location.

One-way analysis of variance was performed on mean RT for each condition. There were significant main effects of Location for the Fixed Location and the Random Location conditions ($F_{3,63}$=24.30, p<.001; $F_{3,63}$=30.98, p<.001, respectively). For the Fixed Location condition, the multiple comparison indicated that the RTs at the 10°, 20°, and 30° locations were significantly longer than the RT at the 0° location (p<.05, p<.01, p<.001, respectively). For the Random Location condition, the RT at the 30° location was significantly longer than the RTs at the 0° and 10° locations (p<.01, respectively). One-way analysis of variance was performed on mean RT for each location. There were significant main effects of Condition for the 0° and 30° locations ($F_{1,21}$=22.05, p<.001; $F_{1,21}$=32.82, p<.001, respectively). These results indicate that the mean RT in the Random Location condition was significantly longer than the mean RT in the Fixed Location condition at the 0° and 30° locations.

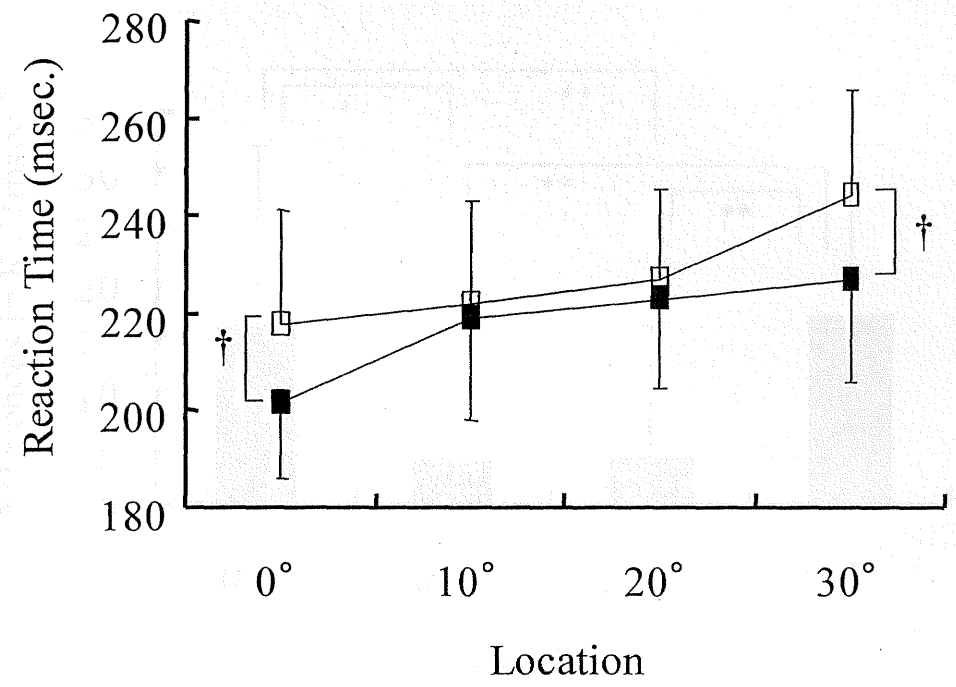

Fig.1 Means and standard deviations of RT for each condition and location. There were significant differences between the Fixed Location (■), and the Random Location (□) conditions at the 0° and 30° locations. † *p<.001*.

Fig.2 shows the means and standard deviations of mean differences in RT between the Fixed Location and the Random Location conditions for each location. Friedman's nonparametric one-way analysis of variance was performed on the differences in the RT between conditions, indicating that the mean difference scores in RT significantly differ between locations [χ_3^2, (N=22)=21.85, p<.001]. A Wilcoxon Paired Signed Rank Test showed that the differences at the 0° location were significantly larger than those at the 10° and 20° locations (p<.05, p<.01, respectively) and that the differences at the 30° location were significantly larger than those at the 10° and 20° locations (ps<.01, respectively).

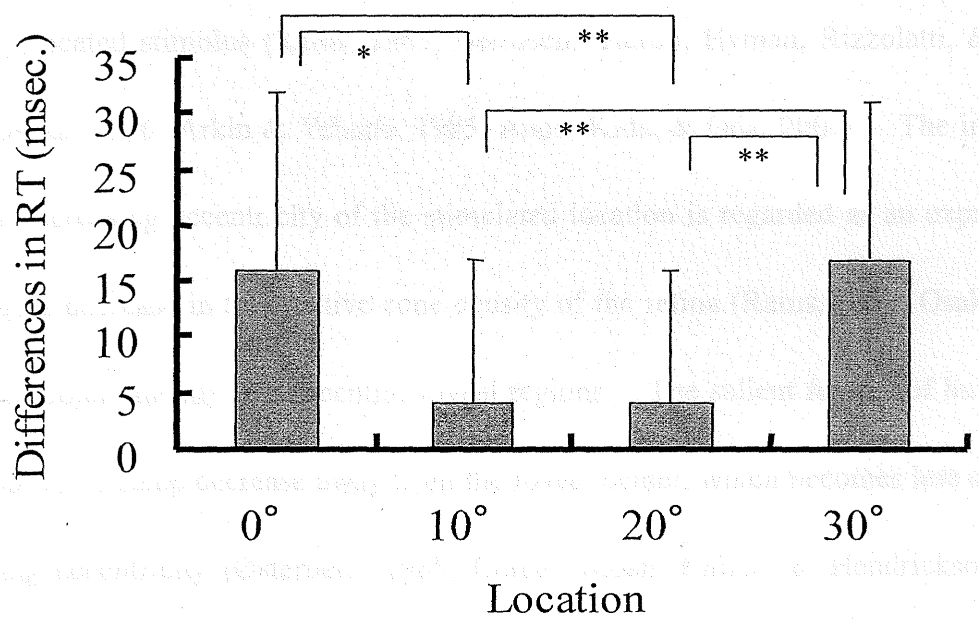

Fig.2 Means and standard deviations of differences in RT between the Fixed Location and the Random Location conditions for each location. Differences at the 0° location were significantly larger than those at 10° and 20° locations. The differences at the 30° location were significantly larger than those at the 10° and 20° locations. ***p<.05. **p<.01.***

DISCUSSION

The present results show that attention was not evenly distributed within the large area of the visual field in the Random Location condition. It seems likely that the RT in the Random Location condition was influenced by not only the simple effect of eccentricity but also by attentional focus.

In the Fixed Location condition, RTs at the 10°, 20°, and 30° locations were significantly longer than the RT at the 0° location and increased gradually with increasing eccentricity. It is known that RT to a peripherally located stimulus is longer than to a centrally located stimulus (Rains, 1963; Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971; Osaka, 1976; Arkin & Yehuda, 1985; Ando, Kida, & Oda, 2001). The increase in RT with increasing eccentricity of the stimulated location is regarded as an expression of the gradual decrease in the relative cone density of the retina (Rains, 1963; Osaka, 1976). Cones are found mostly in the central foveal regions. The salient feature of human cone topography is a steep decrease away from the foveal center, which becomes less steep with increasing eccentricity (Østerberg, 1935; Curcio, Sloan, Kalina, & Hendrickson, 1990). It appears that the findings for RTs in the Fixed Location condition are well consistent with the previous reports showing gradual decrease in the relative cone density in the periphery, and it is assumed that eccentricity itself had similar effects in both viewing conditions in the present study. On the other hand, in the Random Location condition, the RT at the 30° location was significantly longer than the RTs at the 0° and 10° locations. According to our hypothesis, the results in the Random Location condition, as compared with the Fixed Location condition, are presumably attributable to the effects of the attentional focus.

What is intriguing result in the present study was that there were no significant differences in the mean RT between conditions at the 10° and 20° locations, while the RTs in the Random Location condition were significantly longer than those in the Fixed Location condition at the 0° and 30° locations. Furthermore, the differences in RT between conditions were larger at the 0° and 30° locations than those at the 10° and 20° locations. Klein and McCormick (1989) and McCormick and Klein (1990) indicated that under conditions of uncertainty about which of two locations to attend subjects might focus attention on a visual channel that is spatially intermediate, which they called a midlocation placement strategy. It seems likely that the results of the present study can be explained by the midlocation placement strategy. In other words, attention was oriented to intermediate locations, i.e., 10° and 20° locations, out of four locations within large area of the visual field in the Random Location condition.

One model to account for spatial attention in the visual field is that attention can be distributed in a graded fashion, with maximal processing at the attentional focus, which gradually falls off with increasing distance from this focus (Downing & Pinker, 1985; Shulman, Wilson, Sheehy, 1985). It appears that the attentional gradient model can account for the present results. According to this model, the possible explanation for the present results can be that attention got concentrated over the 10° and 20° locations and diminished at the 0° and 30° locations.

In conclusion, attention was oriented to intermediate locations when a visual stimulus was presented randomly within the large area of the visual field.

6 .The effect of incremental exercise on reaction time for the peripheral visual field

In competitive sports, participants are required to perform perceptual and decision-making tasks during strenuous exercise. Performance in sports would be closely associated with both physical and psychomotor skills. Although psychomotor skill is just one aspect of performance, the key difference between good performance and poor performance may be psychomotor skill as well as physical skill.

Reaction time (RT) is one of the many variables involved in psychomotor skill, and it is a prime determinant to evaluate psychomotor performance. Many researchers have examined the effect of exercise on RT (e.g., Brisswalter, Collardeau, & René, 2002; Tomporowski, 2003 for reviews). It should be noted, however, that findings concerning the effect of exercise on RT have been one of the most controversial issues. The controversy may be mainly due to the variety of the protocols, differences in the level of physical fitness of subjects, and motivational factors (e.g., Tomporowski & Ellis, 1986).

It has been hypothesized that exercise induces changes in the level of arousal of the central nervous system. As a result, improvement or deterioration in RT has been explained by changes in exercise-induced arousal. The most influential proposal may be the inverted-U relationship between arousal and RT as descriptive model for interpreting results (e.g., Anderson, 1990; Levitt & Gutin, 1971; Sjöberg, 1975). Chmura and colleagues (1994; 1998) suggested that increases in plasma adrenaline and noradrenaline concentrations during exercise may be indicative of changes in the level of the arousal of the central nervous system. However, the concept of arousal and the inverted-U relationship between arousal and psychomotor performance has been challenged, probably because of the lack of direct evidence for this explanation (e.g., Neiss, 1988).

Visual field is composed of central and peripheral components. Information presented in the central and peripheral visual fields is processed through central and peripheral retinal areas and higher processing areas. There were several studies which shed light on the effect of exercise on psychomotor performance in the peripheral visual field, such as peripheral visual sensitivity (Verriest, De Landtsheer, Uvijls, Claeys, Cobbaut, & Van Langenhove, 1984), peripheral threshold detection (Fleury & Bard, 1987), and vocal RT to visual stimuli presented in the peripheral visual field (Côté, Salmela, & Papathanasopoulu, 1992; Salmela & Ndoye, 1986). In the study of Salmela and Ndoye (1986), vocal RT for the peripheral visual field was measured at rest and during incremental exercise. The results indicated that vocal RT for the peripheral visual field decreases at heart rate (HR) 115, and increases at higher workload where heart rate increased over 145 (Salmela & Ndoye, 1986). They speculated that improvement in vocal RT began to be reversed during exercise interval from HR 115 to HR 145. The number of studies investigating the effect of exercise on RT for the peripheral visual field is few, and the workload where RT for the peripheral visual field may begin to increase is not well documented and remained to be clarified.

The ventilatory threshold (VT) may provide good index of aerobic fitness. Irrespective of underlying mechanism, the VT can be considered to be an important assessment of the availability of the cardiovascular and pulmonary system (e.g., Wasserman, Beaver, & Whipp, 1990). Thus, there might be a close relationship between increase in RT for the peripheral visual field during strenuous exercise and physiological changes around the VT. The main purpose of the present study was to examine the effect of incremental exercise on RT for the peripheral visual field and to determine whether physiological changes around the VT are critical for increase in RT for the peripheral visual field.

The relationship between physical fitness of individuals and cognitive performance is controversial (e.g., Etnier, Salazar, Landers, Petruzzello, Han, & Nowell, 1997; Brisswalter, *et al.*, 2002; Tomporowski, 2003). Physically fit individuals may be able to compensate for the negative effects of strenuous exercise when they perform cognitive tasks under fatiguing conditions (Tomporowski & Ellis, 1986). Therefore, the differences in the level of physical fitness may play a critical role for increase in RT for the peripheral visual field during incremental exercise. In the present study, we also examined the relationship between increase in RT during incremental exercise and maximal oxygen uptake of each individual as an index of physical fitness.

METHOD

Subjects

Nine healthy male subjects (mean ± SD, age = 24.1 ± 1.9 yr; height = 173.4 ± 7.2 cm; mass = 67.3 ± 6.0 kg; VO_{2max} = 48.9 ± 3.8 ml · kg^{-1} · min^{-1}) participated in the present study. Informed consent was obtained from all subjects following a detailed explanation of experimental procedures. The subjects were instructed to refrain from engaging in strenuous exercise for 48 hours prior to each experiment. None of the subjects were free of metabolic, neuromuscular, cardiovascular disorders and recent illness.

Experimental Procedure

The experiment was performed on 2 nonconsecutive days. On the first day, the subjects performed an incremental exercise test until exhaustion to determine maximal VO_2 (VO_{2max}) on a cycle ergometer (Combi 232CXL, Tokyo, Japan). Following warm-up exercise at 20w for 2 min, the ramp exercise test at the cadence of 60 rpm started with a 10w increment every minute until the limit of the subject's tolerance was reached.

On the day of the main study, the subjects were given a familiarization period of three blocks of RT tasks during unloaded cycling before taking part in the experiment. At the beginning of the experiment, the subjects rested for 5 min on the cycle ergometer. RT measurement was performed 3 min and 30 sec later after the start of the rest period. The RT at rest was measured to establish baseline of RT task. Afterwards, subjects performed RT tasks during cycling in the Exercise and the Control conditions. The subjects were instructed to cycle at a cadence of 60rpm and were instructed to maintain the cadence throughout all subsequent exercise tests. One of the experimenters monitored the cadence throughout the experiment, and gave feedback verbally when the subjects were not able to maintain the cadence. Five subjects performed the Exercise condition first and the rest four performed the Control condition first. Both conditions were performed with one visit to the laboratory. The interval between conditions was at least 1 hour. A new condition was started after the subject's heart rate had reached to the resting level.

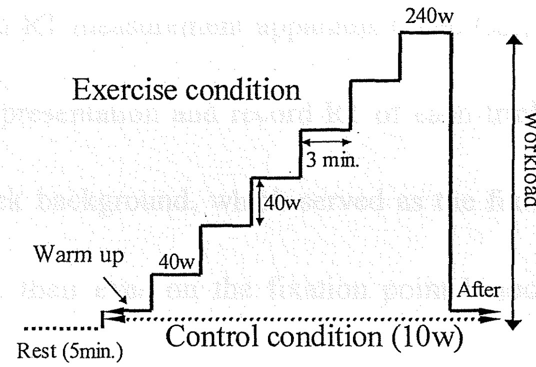

Fig.1 Experimental protocol

Experimental protocol was shown in Fig.1. In the Exercise condition, RT was measured during the exercise and immediately after the exercise. At the beginning of the Exercise condition, the subjects cycled at 10w for 3min as warm-up exercise. Following warm-up exercise at 10w for 3 min, the subjects cycled at 40w for 3 min, increasing by 40w every 3 min until 240w. During the exercise, RT measurements were performed 1 min and 30 sec later after the start of every increase in workload. After the exercise, the subjects cycled at 10w for 3 min in order to measure the RT immediately after the exercise. RT after the exercise was measured 15 sec later after the end of exercise at 240w. The subjects continued to cycle after the RT measurement until 3 min had passed.

In the Control condition, the subjects cycled at 10w for 24 min. RT measurements were temporally matched with the measurements in the Exercise condition. This control condition was included to determine effects of time course on RT and potential practice effects arising from repeated RT tasks.

RT Measurement

A computer and RT measurement apparatus (Qtec Co., Ltd., Japan) were used to control visual stimulus presentation and record RT of each trial. A white fixation cross was presented on a black background, which served as the fixation point. The subjects were instructed to keep their eyes on the fixation point binocularly throughout the RT measurement, and were reminded about the importance of maintaining fixation. A visual stimulus was a white filled circle, 5mm in diameter (22.0 cd/m^2). The visual stimulus randomly appeared at 15° to the right or left from the midpoint of the subject's eye and was separated by an irregular inter-stimulus interval varying 2s to 4s. The exposure duration of the visual stimulus was 100 msec. One block of the RT task consisted of 20 trials. Total time for the one block was 1 min. The subjects were instructed to react to the stimulus onset as quickly as possible by pressing the response button on the right handlebar with the right thumb.

During the RT measurement, the subjects faced the computer screen with the head on a chin rest so the eyes were directly in front of and level with the position of the fixation point. The chin rest was positioned at the middle of the handlebars. The distance from the chin rest to the screen was 55cm. The subjects were instructed not to stabilize their head on the chin rest while RT was not measured. The horizontal components of eye movement were recorded using electrooculogram (EOG) during the RT measurement. Trials in which overt eye movements were detected were discarded without replacement. In addition, RT less than 140ms or greater than 500ms was removed as outliner prior to the analysis.

Gas exchange parameter and Heart rate Measurements

Measurements of gas exchange parameters were continuously obtained using the mixing chamber method (AE-280S, Minato, Japan). The analogue signals of fractional concentrations of O_2 and CO_2 from the gas analyzers and those from the flow transducer were continuously digitized using a 13 bit analogue-to-digital converter at a sampling rate of 50 Hz. O_2 uptake (VO_2), CO_2 output (VCO_2), minute volume (VE), respiratory exchange ratio (R), and ventilatory equivalent for O_2 (VE/VO_2) and CO_2 (VE/VCO_2) were calculated every 15s. Gas exchange parameters were used to determine ventilatory threshold (VT). The VT was determined according to our previously described procedures (Moritani, Berry, Bacharach, & Nakamura, 1987). In brief, the VT was determined by use of respiratory exchange parameters, i.e., nonlinear increase in VE and VCO_2, abrupt increase in the fraction of O_2 in expired air and R and systematic increase in VE/VO2 without any increase in VE/VCO2 (Wasserman, Whipp, Koyal, & Beaver, 1973).

For the assessment of HR, an electrocadiogram (ECG) was recorded throughout the experiment. The analogue output of the ECG was connected to an ECG amplifier (Multi-channel Amplifier MEG-6100, Nihon Kohden Co., Japan) and digitized using a 13 bit analogue-to-digital converter (HTB410) at a sampling rate of 1kHz, using a 0.5 Hz-100 Hz band pass filter at rest and a 1.5 Hz-100 Hz filter during exercise.

Before the experiment, we confirmed that the subject's view of the computer display was not cut off by the measurement apparatus of gas exchange parameter. Gas exchange parameters and HR during the initial 2 min at rest were discarded to observe the steady-state responses, and the remaining 3 min bins were used for analyses.

Statistical Analysis

All data are expressed as means ± SD (table) or SE (figures). Values of VO_2, HR were averaged for last 3 min at rest, for each workload in the Exercise condition, and for each temporally matched period (3 min) in the Control condition. Comparison of values of RT, VO_2, and HR between the Exercise and the Control conditions was performed by paired t-tests. The Dunnett paired t-test was used to determine the significance of differences in the values between rest period (baseline) and each workload in the Exercise condition, and between rest period and each period in the Control condition. Additionally, repeated-measured ANOVA followed by a Tukey's post hoc analysis were used where appropriate. Differences with a probability level of < 0.05 level were designated as significant.

RESULTS

VO_2 and HR

VO_2 and HR in the Exercise and the Control conditions are shown in Table1. VO_2 and HR in the Exercise condition increased linearly as a function of exercise intensity. VO_2 was significantly larger in the Exercise condition than in the Control condition during and after the exercise ($p<0.001$, respectively). Each value of VO_2 in the Exercise and the Control conditions was significantly larger than VO_2 at rest ($p<0.001$, respectively).

Table 1 VO2 and HR at rest, in the Exercise condition, and in the Control condition.

		Workload in the Exercise condition, watts						
		40W	80W	120W	160W	200W	240W	After
VO_2, ml/kg/min								
Exercise		10.4±1.0	15.5±1.2	21.3±1.7	27.8±2.3	34.4±2.9	41.0±2.9	18.4±1.2
Control		6.9±1.1	6.8±0.8	6.9±0.8	6.7±0.9	6.7±0.8	7.1±0.9	6.9±0.9
Rest	4.1±0.6							
Heart Rate, bpm.								
Exercise		88.4±13.8	103.1±13.9	122.1±11.4	145.5±10.0	165.4±6.6	176.1±7.7	147.3±9.1
Control		80.8±10.2	81.3±9.9	82.1±10.5	82.3±10.9	82.6±10.3	82.8±10.2	82.2±9.7
Rest	71.5±8.5							

Note that exercise workload in the Control condition was 10w throughout the condition.

HR was significantly larger in the Exercise condition than in the Control condition during the exercise except for the 40w (at 80w, $p<0.01$; at 120w-240w, $p<0.001$). HR after the exercise in the Exercise condition was also larger than in the Control condition ($p<0.001$). Each value of HR in the Exercise and the Control conditions was significantly larger than HR at rest ($p<0.001$, respectively).

RT for the Peripheral Visual Field

RT errors, including eye movements, were rare (less than 1.6%) and were not analyzed. RTs for the peripheral visual field at rest, in the Exercise condition, and the Control condition were shown in Fig.2.

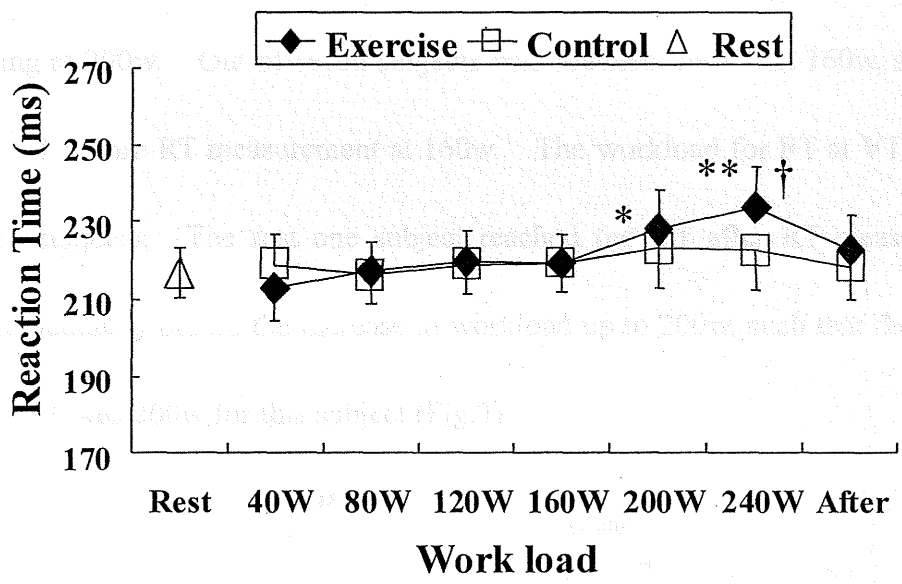

Fig.2 RT for the peripheral visual field at rest (△), in the Exercise condition (◆), in the Control condition (□). Note that exercise workload in the Control condition was 10w throughout the condition.

The RTs at 200w and at 240w in the Exercise condition were significantly larger than at rest. The RT at 240w in the Exercise condition was significantly larger than the RT measured in the same time course in the Control condition. There was no difference in the RT between at rest and after the exercise in the Exercise condition. In the Control condition, no differences were observed in the RT between at rest and during cycling.

We determined whether physiological changes immediately after the VT are critical for increase in RT for the peripheral visual field. For this analysis, in the present study, RT at the VT was defined as the RT measured immediately after each subject reached the VT. None of the subjects reached the VT during the RT measurement. Seven subjects reached the VT during cycling at 160w, and the rest two reached the VT during cycling at 200w. Out of seven subjects who reached the VT at 160w, six subjects reached the VT before RT measurement at 160w. The workload for RT at VT was 160w for these six subjects. The rest one subject reached the VT after RT measurement at 160w and immediately before the increase in workload up to 200w, such that the workload for RT at the VT was 200w for this subject (Fig.3).

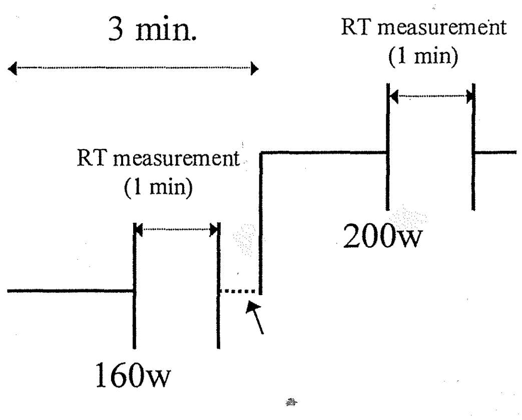

Fig.3 Time course during exercise at 160w and 200w in the Exercise condition. The arrow (→) indicates the time when one subject reached the VT. For this subject, RT at the VT was defined as the RT measured during exercise at 200w.

Therefore, the workload for RT at the VT was 160w for six subjects and 200w for the rest three. Similarly, RT below the VT was defined as the RT measured immediately before each subject reached the VT. RT above the VT was also defined as the RT measured at 40w heavier workload than the workload where RT at the VT was measured.

Fig.4 illustrates the RT at rest, below the VT, at the VT, and above the VT. The Tukey's multiple compassions indicated that the RT above the VT was significantly larger than the RT at rest and below the VT (p<0.01, respectively). The difference in the RT between at the VT and above the VT did not marginally reach significance (p=0.054). There was no difference in the RT between below VT and at the VT. These results indicated that RT did not increase immediately after the subjects reached the VT, but increased at the workload above the VT.

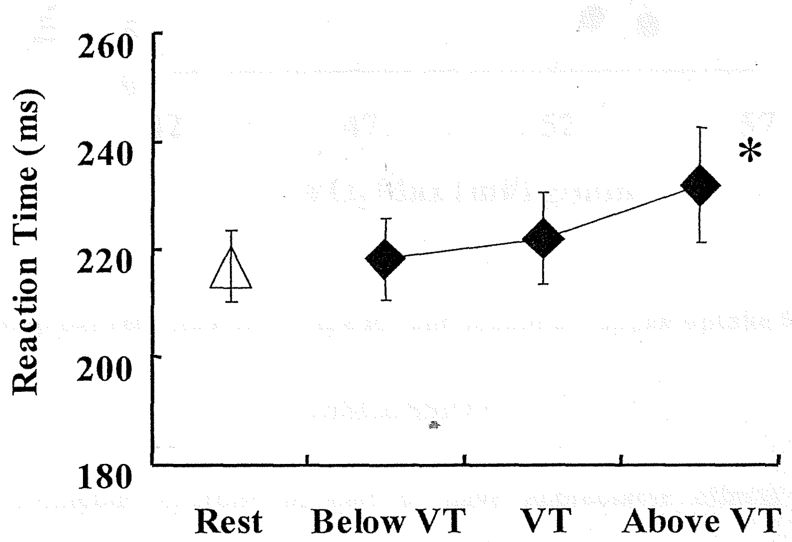

Fig.4 RT for the peripheral visual field at rest, below the VT, at the VT, and above the VT.

Fig.5 shows the relationship between the increase in the RT in the Exercise condition and VO_{2max}. All data were plotted individually. The increase in the RT was calculated by subtracting the RT at rest from the RT at 240w. The RT at 240w in the Exercise condition was larger than the RT at rest for all subjects. The increase in the RT negatively correlated with the VO_{2max} for each subject ($r = -0.73$, $p<0.05$), indicating that the higher the physical fitness of each individual, the smaller the increase in the RT for the peripheral visual field during the exercise at high workload.

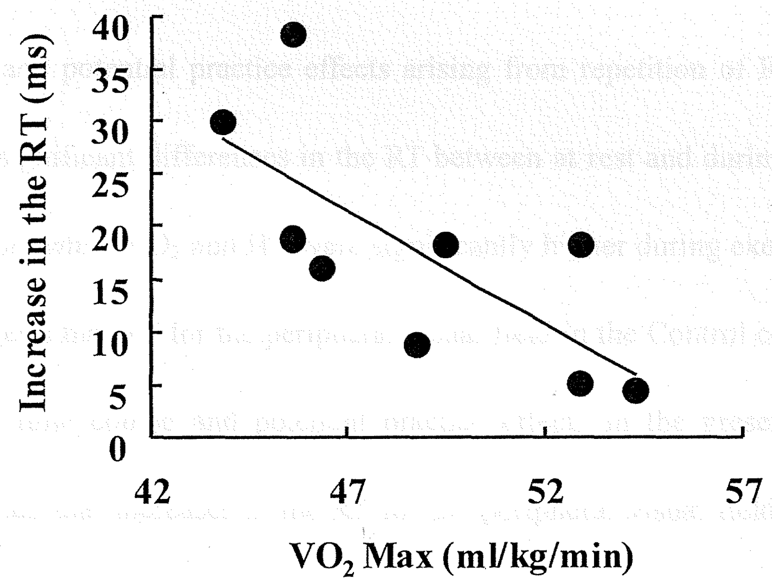

Fig.5 Relationship between increase in the RT and maximal oxygen uptake for each subject.

DISCUSSION

The incremental exercise appears to have appreciable effects on RT for the peripheral visual field. The present study indicated that RT for the peripheral visual field increased at workload above the VT, while there were practical no changes in the RT during exercise below and immediately after the VT. These results suggest that physiological changes around the VT are not effective enough to deteriorate speed of response to stimulus presented in the peripheral visual field. In addition, the increase in the RT, which was calculated by subtracting the RT at rest from the RT at the highest workload, negatively correlated with the VO_{2max} for each individual. It is likely that the differences in the level of physical fitness of the individuals play a critical role for the increase in the RT for the peripheral visual field.

In the present study, the Control condition was performed to determine the effects of time course and potential practice effects arising from repetition of RT measurement. There were no significant differences in the RT between at rest and during exercise in the Control condition, while VO_2 and HR were significantly higher during exercise than at rest. This result suggests that RT for the peripheral visual field in the Control condition was not affected by the time course and potential practice effects in the present study. It is, therefore, assumed that increases in the RT for the peripheral visual field in the Exercise condition are due entirely to the effects of exercise.

RT for the peripheral visual field increased during exercise above the VT. This result may suggest that physiological changes induced by strenuous exercise above the VT deteriorated speed of response to the stimulus in the peripheral visual field. One possible explanation for the increase in the RT for the peripheral visual field may be that physiological changes induced by exhaustive exercise deteriorated the perceptual ability in the peripheral visual field.

Kobrick and Dusek (1970) and Kobrick (1972; 1974) indicated that RT for the peripheral visual field increases during exposure to hypoxic conditions. Similarly, cognitive RT also increases during hypoxemia (Noble, Jones, & Davis, 1993; Van der Post, Noordzij, De Kam, Blauw, Cohen, & Van Gerven, 2002). It is known that exercise induces hypoxemia and arterial oxyhemoglobin desaturation (e.g. Dempsey, Hanson, & Henderson, 1984; Dempsey & Wagner, 1999). Nielsen, Boushel, Madsen, and Secher (1999) evaluated cerebral oxygenation of competitive oarsmen during maximal ergometer row and maximal cycling. Cerebral oxygenation decreased during maximal ergometer row. On the contrary, cerebral oxygenation was not reduced during maximal cycling (Nielsen, *et al.* 1999). In the present study, exercise was not maximal cycling, and workload was not more than 85% of VO_{2max} even at the highest workload. However, subjects in the present study were not highly trained (mean VO_{2max}, 48.9 ml · kg^{-1} · min^{-1}), as compared with the study of Nielsen, *et al.* (1999). Therefore, oxygen supply to some regions in the brain, related to visual stream from peripheral retina to higher visuomotor processing, might decrease during exercise at workload above the VT for the subjects in the present study. Taken together, regional decrease in oxygen supply to the brain might, at least in part, explain the deterioration in perceptual ability in the peripheral visual field during strenuous exercise in the present study.

We do not have data to show regional decrease in oxygen supply in the present study and our explanation for the increase in the RT for the peripheral visual field would be speculative. However, the present results that the increase in the RT for the peripheral visual field negatively correlated with the VO_{2max} for each individual (Fig.4) may be in line with our explanation. Physically fit individuals showed shorter simple and choice RT (Offenbach, Chodzko-zajko, & Ringel, 1990; Spirduso, 1980) and shorter event-related potentials latencies (Dustman, Emmerson, Ruhling, Shearer, Steinhaus, Johnson, Bonekat, & Shigeoka, 1990). Dustman, *et al.* (1990) speculated that performance superiority of the physically fit individuals was, at least in part, the results of more oxygen being available for cerebral metabolism. This may lead to the notion that, since physically fit individuals had higher oxygen-carrying capacity of blood, they might be less subject to the negative effect of the increase in the RT for the peripheral visual field. It can be said that the differences in the level of physical fitness of individuals play a critical role for the increase in the RT for the peripheral visual field.

Another possible explanation for the present results may be the effect of dual task. On the dual task paradigm, one motor task is performed simultaneously with another motor task. It has been suggested that attentional resources are limited, and that, in the dual task, increase in allocation of attentional resources to one motor task leads to decrease in allocation of attentional resources to the other motor task (e.g., Schmidt & Wrisberg, 2000). Thus, it is assumed that deterioration of performance in one motor task reflects the difficulty of the other motor task and eventual attentional demand on the task.

An electroencephalogram study indicated that P300 amplitudes in an oddball task decreased during cycling, suggesting that attentional resources allocated to the oddball task decreases during exercise (Yagi, Coburn, Estes, & Arruda, 1999). Brisswalter, *et al.* (2002) claimed that the effect of dual task was strongly related to energetic constraints of the exercise when cognitive task was performed during exercise. They suggested that the greater the energy demand, the more attention is required to control movements. In the present study, the increase in the RT was observed only at high workloads above the VT. It is, therefore, possible that the more attentional resources were allocated to pedaling exercise at high workload above the VT in the present study. Taken together, second possible explanation for the increase in the RT for the peripheral visual field may be that attetional resources allocated to the RT task decreased during exercise at high workloads above the VT. Workloads below and immediately after the VT might not be effective enough to allocate more attentional resources to exercise.

The RT for the peripheral visual field did not decrease during exercise at low and moderate workloads in the present study, inconsistent with the study of Salmela and Ndoye (1986). Chmura, *et al.* (1994; 1998) showed that choice RT decreases during exercise below and above LT. Similarly, facilitating effects during exercise on cognitive performance were observed in complex tasks (Collardeau, Brisswalter, Vercruyssen, Audiffren, & Goubault, 2001; Yagi, *et al.* 1999). It would be important to emphasize that speed of performance on complex tasks is facilitated by exercise, while performance on simple tasks is unaffected (McMorris & Graydon, 2000). The task in the present study was simple response task. Thus, it is not surprising that exercise below and immediately after the VT did not improve the simple RT for the peripheral visual field. The failure of improvement in RT performance in the present study may be attributable to the task simplicity.

Finally, in the present study, no difference was observed in the RT between at rest and immediately after exercise, while VO_2 and HR immediately after the exercise was higher than at rest. It may be suggested that the subjects recovered from deterioration in perceptual ability in the peripheral visual field soon after exhaustive exercise and/or the effect of dual task disappeared since energetic constraints were very low (10w) after exercise.

In conclusion, RT for the peripheral visual field increased at high workload above the VT during incremental exercise. The present results may suggest that the increase in the RT for the peripheral visual field are due to deterioration in perceptual ability in the peripheral visual field and/or decrease in attentional resources allocated to the RT task. The differences in the level of physical fitness of the individuals play a critical role for the increase in the RT for the peripheral visual field. Further research would be required to elucidate factors attributable to the increase in RT for the peripheral visual field during exhaustive exercise.

7 .General Discussion

The ability to respond quickly to the sensory input is a prime determinant of human psychomotor skill. This ability would be a contributing factor to good performance in most sports. In a series of studies, we have clarified that speed of response to a peripheral visual stimulus is influenced by several factors, such as experience of ball sports, practice, attention, and physiological changes induced by incremental exercise. These findings have important suggestions to motor activities based upon the visual input from the peripheral vision as well as central vision.

In the first study, soccer players showed shorter premotor time during central and peripheral visual RT tasks compared to nonathletes. This result suggests that the soccer players are better able to respond quickly to stimuli presented to both central and peripheral locations. It might be speculated that soccer players might have inherited the peripheral perceptual abilities to respond quickly. Alternatively, soccer players may have developed higher abilities through daily training and games, suggesting that the speed of response to a peripheral stimulus may potentially improve as a consequence of practice.

In the second place, we examined the practice effect on RT for the peripheral visual field in order to verify the speculation that speed of response to a peripheral stimulus improves with practice, showing that the RT for the peripheral visual field decreases with practice. More interestingly, the practice effects on the RT for the peripheral visual field extended to RT for the central visual field, vice versa. The transfer effects observed in this study may suggest that the decrease in the RT with practice have resulted from a decrease in the central nervous system's processing time in common between central and peripheral RT tasks. In addition, the practice effects and the transfer effects were stable and retained for three weeks. These results suggest that once the neural correlates of responding quickly are improved, the improved performances are maintained over the retention interval.

Thirdly, it was indicated that attention was oriented to intermediate locations when a visual stimulus was randomly presented within the large area of the visual field including central and peripheral visual fields. This finding may suggest that subjects, consciously or unconsciously, adopt the strategy to orient attention to intermediate location in order to respond as quickly as possible to all stimuli presented within the large area of the visual field. It should be noted, however, that the strategy adopted in this study may not be always the case. Attentional distribution would depend on the task demands.

The fourth study showed that RT for the peripheral visual field increased at workload above the Ventilatory Threshold (VT), while there were practical no changes in the RT during exercise below and immediately after the VT. One possible explanation for these results may be that the transient metabolic imbalance in the brain regions during exhaustive exercise deteriorated the speed of response to a peripheral stimulus. The results that the differences in the level of aerobic physical fitness of the individuals play a critical role for the increase in the RT might suggest that oxygen supply to brain has a close relationship with the increase in the RT during exhaustive exercise. Another possible explanation for the results of this study may be that attetional resources allocated to the RT task decreased during exercise at high workloads above the VT. The finding in this study might help to explain the difficulty in using peripheral vision during exhaustive exercise.

In conclusion, the ability to respond quickly to a peripheral stimulus may be improved by experience of ball sports, practice of reaction time tasks, and highly trained aerobic fitness. It is assumed that these factors would be mutually interactive. Peripheral vision would be critical for performing a variety of motor activities. The performance in sports may potentially be improved as a consequence of improvement in speed of response to the sensory input from peripheral vision.

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